

A METHOD FOR PLANNING OF ROAD SIGN SYSTEM IN HIGHWAY USING STRAYING INDEX

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Abstract: In this paper we propose a mathematical model and its algorithm to build the optimum road sign system that keeps drivers on their original course. We assumed that signs were posted only at the entrance of intersections. Furthermore we defined the Straying Index as an expression of drivers straying and proposed a method for minimizing the total Straying Index of all OD. In this method, the total Straying Index of drivers was taken as the objective function, while the number of links where signs were to be posted and the numbers of displays for one direction on the signboard were treated as the restrictions. We solved this problem through the analysis of a small network example using dynamic programming and extracted some properties of sign type by taking into account such characteristics as place name, route number, and the combinations of both.

Key Words: road sign system, traffic information, straying, traffic control, network analysis, optimization

1. INTRODUCTION

Basic road traffic information is obtained by drivers from guide information such as place names and route numbers (Mitsuda, 1984). The purpose of the installation of road signs is to lead drivers unfamiliar with the area in the right direction without straying off course or causing anxiety. Also,

reducing the number of drivers who have strayed off course are expected to bring about a number of positive effects, such as the alleviation of traffic congestion, reductions in travel time, the prevention of traffic accidents, and reductions in energy consumption and gas emission. The contents of course guidance are generally the positioning of road signs in the road network and the displaying of information so as to minimize the straying of drivers. This idea is effective from the viewpoint of constructing a rational road sign system on the road network.

Next we review the existing studies on course guidance using road signs. Firstly, the existing studies on the evaluation of road sign systems are as follows: Mitsuda (1984) introduced the theory of a continuous guide network to establish the rules for the consistency of display contents. Kurimoto (1979) proposed a method for evaluating the effects of guide signs installed at the entrances of intersections over the entire road network. Wakabayashi (1990,1991) proposed a mathematical model for evaluating the ease of reaching the destination.

The findings from studies on visual recognition of signs are as follows: Okura *et al.*(1981) analyzed the relationship between the amount of information provided by the number of place names displayed for each direction and sign readability. Nosaku *et al.*(1988) numerically evaluated the degree of visual recognition effects of some types of road signs and reflection plates based on actual driving investigations. Ishiwatari *et al.*(1997) developed a travel simulator, which enables drivers to evaluate course guide signs, and compared the level of driver anxiety between experimental and actual driving conditions. Takamatsu *et al.*(1997) proposed the utilization of pulse numbers as indexes instead of questionnaires, and they verified the effectiveness of this method by using the travel simulator and actual driving experiments. Furthermore, Kimura *et al.* (1997) verified the distances and times required for reading road signs, using CG images to evaluate the readability of the signs, and they studied the relationship between distance and time.

Toi(1992,1992) proposed an optimization technique for minimizing straying as well as the number of road signs that would need to be installed by using information entropy, based only on the place name guide, in order to study the optimum arrangements of road signs on the road network. In addition to Toi's method, Nomura *et al.*(1996) introduced a new objective function to equalize straying in each OD, and we expanded Toi's method regarding guide systems using only route numbers. However, in this model we were unable to introduce place names and routes simultaneously. Nomura *et al.*(1997) also proposed an optimization technique assuming the route guide as a primary problem and the place name guide as a secondary problem.

Incidentally, almost all of these studies focus only on allowing drivers to be able to reach their destinations without straying, and no study takes any measures into consideration for assisting lost drivers. Naturally it is impossible to guide the actual course for each OD completely. Therefore it is preferable to provide a function to show an alternative course for the drivers to whom the shortest course has not been guided due to various restrictions. Furthermore, since drivers unfamiliar with the area tend to miss guide information, the straying of drivers can occur

even on road networks where the guide system is theoretically complete. The desired guide system should be also expected to assist lost drivers. That is, the guide system should be programmed to have a function to lead straying drivers back to the planned course or its alternatives. In order to study this problem, it is necessary to clarify the effects of road signs on the prevention of straying and to construct a guide system by optimizing the system.

From these viewpoints, in this study we defined the Straying Index of drivers and proposed a mathematical model to obtain a guide system that minimizes the total Straying Index on the road network and corresponds to the road sign arrangement and the information contents of the signs.

2. OPTIMIZATION TECHNIQUE FOR ROAD SIGNS

Generally speaking, the primary purpose of road signs is to lead drivers to their destination via the shortest possible route, and the secondary purpose is the minimization of driver straying. However, if the secondary purpose is achieved, then the primary purpose can also be sufficiently achieved in almost all cases. Furthermore, from the social viewpoint, it is generally considered that a guide system that minimizes driver straying has a higher social value than one that simply leads drivers through the shortest possible course. From this viewpoint, in this study we consider the ideal features of a guide system designed to minimize driver straying.

(1) Method for Guiding

As for methods for guiding drivers to their destinations, some argues that the route guide system is more useful than the place name guide system because it offers consistency of course guides (Mistuda,1984). On the other hand, the place name guide system has three main purposes. The first is to lead drivers to their proper destinations in an urban road network, the second is to provide a means for checking the traveling direction and current place, and the third is to lead strayed drivers back to the original course or to the right destination even if they fail to return to the original course.

The contents of information that are needed for the route guide system are 1) the current location, 2) the traveling route, 3) the current direction traveling toward, and 4) the direction to be taken at the next intersection. However, there are two types of essential information. One is needed to determine the correct direction to be taken and the other is needed for confirmation. Although it is desirable to consider both of these types at the same time, we decided to express the model for a course guide system first by using information content 4), which is necessary as basic guide information on the road network.

From the viewpoint of road users, it is desirable that all the necessary route numbers and destinations are displayed. However, a sign plate does not have enough space to display many destination names, and the drivers do not have enough time to read all the information.

Furthermore, it is necessary to express the displayed contents as simply and appropriately as possible in order to improve visual recognition. Therefore, in this study we propose a method for constructing a guide system in which the place names are displayed in combination with the route numbers at the appropriate locations in order to utilize the advantages of both place names and route numbers as much as possible.

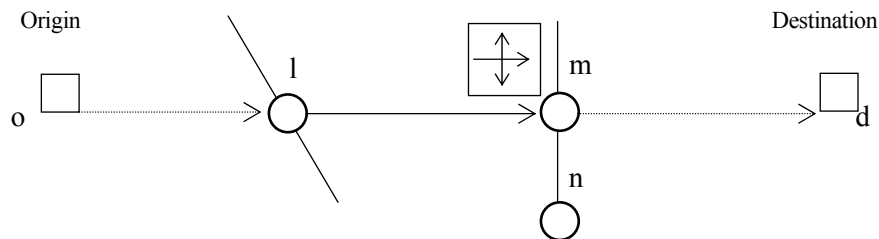


Figure 1. Sign Location on Links.

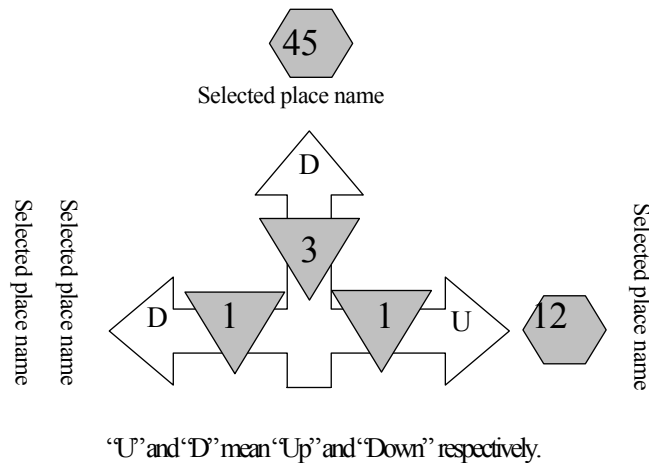


Figure 2. Proposal of Guide Signs.

(2) Assumptions for Modeling

The routes guided by the road signs are set for each combination of OD. In addition, the shortest courses obtained for each OD combination are taken as the basic guide routes. The locations of guide sign installations are assumed to be at the entrance of the intersections as shown in Figure 1. 1. The candidate group S_{mn} for the place names and route numbers in the direction from m to n on the link lm consists of the destination of each OD and the route numbers that pass through the destination. The kinds of information on the planned route are assumed to be the place names, the route numbers, "Up" or "Down" as the direction, and the order of the route guide. The display "Up" or "Down" is introduced here because it is thought that the displayed "Up" or "Down" in addition to the route numbers is effective for drivers who could not obtain the appropriate information from the displayed place names alone.

As shown in Figure 2, the contents to be displayed shall be the route number and its “Up” or “Down” of diverging or crossing routes. The place name or the route number is selected without any overlapping of the directions. The number of place names and route numbers is limited by constant value n_a for each direction. In the example shown in Figure 2, n_a equals 2.

(3) Expression for Installation of Signs and Displayed Content

Firstly, several symbols are introduced to express the installation of signs and the contents to be displayed. In the road section of Figure 1, $x_{lm} = 1$ means that a guide sign is installed at the entrance of the intersection of node m on the link lm , and $x_{lm} = 0$ means that it is not installed. And, $\xi_{lmnj} = 1$ means that the place name or route number j is guided to the direction of the node n , which is adjacent to the node m on the link lm , and $\xi_{lmnj} = 0$ means that it is not guided.

By using these symbols, the policy \mathbf{x} that shows the presence or absence of sign installation on links and the policy $\Xi(\mathbf{x})$ that shows the condition of guidance based on \mathbf{x} can be expressed by the following formula:

$$\mathbf{x} = \{\cdots x_{lm} \cdots\} \quad (1)$$

$$\Xi(\mathbf{x}) = \{\cdots C_{lm} \cdots\}, \quad lm \in M_{od} \quad (2)$$

$$C_{lm} = \begin{bmatrix} \xi_{lmnj} \end{bmatrix}, \quad n \in N_m \quad (3)$$

Where, M_{od} is a set of links in the route between the nodes o and d , and N_m is a set of the adjacent nodes around the node m . C_{lm} is the matrix consisted of ξ_{lmnj} , which shows the guidance condition of place name ‘ n ’ to the direction ‘ j ’. And C_{lm} has a practical meaning when $x_{lm}=1$. These things are expressed by the equation (4) to (6)

(4) Expression of Restriction

The place name or route numbers to guide to each direction are selected from the set S_{mn} of the candidates.

$$C_{lm} \leq x_{lm} \omega_m \quad (4)$$

$$\omega_m = \begin{bmatrix} \omega_{mnj} \end{bmatrix} \quad (5)$$

$$\xi_{lmnj} \leq x_{lm} \omega_{mnj} \quad (6)$$

Where, $\omega_{mnj} = 1$ means that the place name or route number j is included in S_{mn} , and $\omega_{mnj} = 0$ means that it is not included.

The restricted number of place names or route numbers to guide to each direction is n_a .

$$\sum_j \xi_{lmj} \leq n_a \quad (7)$$

Furthermore, when the upper limit of the number of sign installations is assumed to be n_s , n_s is determined from the budget of the road administration.

$$\sum_{lm \in L} x_{lm} \leq n_s \quad (8)$$

where, L is a set of link candidates where signs are installed.

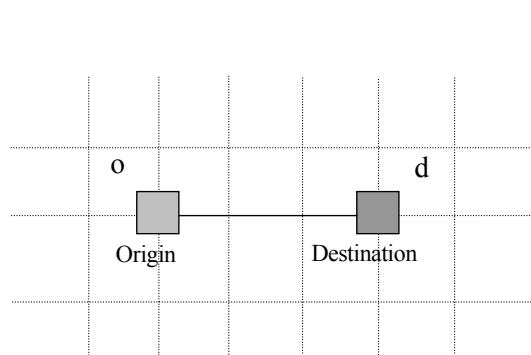


Figure 3. Example of Network.

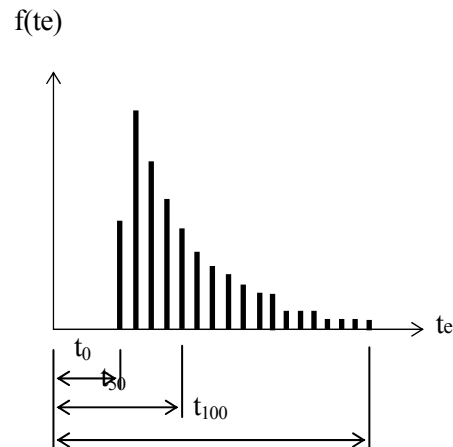


Figure 4. Concept of Reaching Frequency Distribution.

(5) Expression of Straying Index

If there is successive and effective guidance at the entrances of the intersections on each route, the fuzziness of course guide information becomes 0. Now let us consider an infinite network having various link lengths (Figure 3). When a driver, who is unfamiliar with the area, drives to the destination without guidance on this network, it is thought that the time or distance to reach the destination follows a probability distribution. This distribution is illustrated in Figure 4, where t_0 is the time or distance until the first wave, namely the minimum course length of OD, and t_e is the time or distance in which e % of drivers reach the destination. Currently it is thought that the larger the ratio of t_e to t_0 becomes, the more straying occurs. Therefore the evaluation function that we call the "Straying Index" can be defined as follows:

$$H(\Xi(x)) = \sum_e \left(\frac{t_e(\Xi(x))}{t_0(\Xi(x))} - 1 \right) \quad (9)$$

where, $H(\Xi(x))$, $t_e(\Xi(x))$ and $t_0(\Xi(x))$ are the values under the policy $\Xi(x)$.

The Straying Index $H(-)$ is non-negative, and when the distribution form shown in Figure 4 shifts to the left, the Straying Index tends to decrease, indicating a desirable change in conditions. Further, $H(-)=0$ means that all the drivers of a certain OD ride on the first wave shown in Figure 4 and that no straying has occurred. Since the Straying Index represents the degree of driver straying, it is possible to clarify guide effects through the change of the Straying Index based on

the policy $\Xi(x)$.

(6) Concept of Optimization

The drivers expect to lower their chances of straying, while the road administrators prefer to lessen the number of guide signs as much as possible from the viewpoint of budget restrictions, administration time, and landscape. Therefore, the following two ideas can be introduced for the purpose of optimization:

- i) An index regarding the degree of driver straying is adopted as the objective function and it is minimized. Here it is necessary to consider any restraints regarding the maximum number of guide sign installations and displays in each direction, the amount of information on planned routes, and the contents to be displayed.
- ii) The number of guide sign installations is adopted as the objective function and it is minimized. Here it is necessary to establish the restraints regarding the allowable degree of straying as the result of guide service, the maximum number of displays in each direction, the amount of information on planned routes, and the contents to be displayed.

If the objective function and one of the restraints are exchanged with each other, i) and ii) become the same. However, if the installation of guide signs is allowed on all links, i) becomes the concept that determines the contents to be displayed, while ii) would not be considered. Also, it can be said that i) is more general because it is difficult to set the upper limit of the Straying Index. Therefore, in this study we decided to use the total Straying Index of all drivers as the objective function and to minimize it based on the concept of i).

This is an optimal problem to minimize the function Z subject to the restraints relating to the number of guide sign installations and the number of displays in each direction. In other words, if we assume the policy set of guide contents in each direction, including sign installation points to be $\Xi(x)$, and make an optimization problem formula, we obtain

$$\underset{x, \Xi(x)}{\text{Minimize}} \quad Z(\Xi(x)) \quad (10)$$

$$Z(\Xi(x)) = \sum_k H_k(\Xi(x)) \quad (11)$$

Where, the afore-mentioned formulas (1), (2), (5), (7), and (8) are omitted, and k is the OD number. Furthermore, the decision variables for the optimization model shown in the formulas (10) and (11) are x_{lm} and ξ_{lmnj} .

3. SOLUTION

(1) Application of Dynamic Programming

This problem is an optimum resource allocation problem with a nested structure assuming the

sign installed links, guide directions, and guide contents as finite resources. Taking these points into consideration, dynamic programming is useful to solve the problem because it is helpful in modifying the complex structure of non-linear problems to obtain a simple formula and to reduce calculation time reasonably.

Here, either OD or the link may be adopted as a stage variable (Momura *et al*, 1996). In cases where the link is adopted as a stage variable, if the number of sign installations increases, the problem becomes high dimensional and therefore difficult to solve. On the other hand, if OD is assumed to be the stage variable the problem becomes multi-step and one-dimensional and it can be solved with a small amount of calculation. Therefore OD should be assumed as the stage variable.

The policy of guide sign installation, which shows the condition at k-th stage satisfying the restrictions (4)-(8), is represented by x^k , and the guide contents policy is represented by $\Xi(x^k)$. Then the minimum total Straying Index for each OD can be obtained by the following formulas based on dynamic programming:

$$Z_k(\Xi(x^k)) = \min_{\Xi_{k-1}(x^{k-1}) \in \Xi_k(x^k)} [H_k(\Xi_k(x^k) - \Xi_{k-1}(x^{k-1})) + Z_{k-1}(\Xi_{k-1}(x^{k-1}))] \quad (12)$$

$$i.e. \quad Z_1(\Xi_1(x^1)) = H_1(\Xi_1(x^1)) \quad (13)$$

where, $Z_k(\Xi(x^k))$ is the minimum total Straying Index for each OD at k-th stage. The flow diagram of the solution is shown in Figure 5.

(2) Simulation of Straying Index

The link length and number of branches at each intersection vary in the actual network, and since it is difficult to obtain the Straying Index analytically regarding the second and successive waves in Figure 4, the value of formula (9) must be obtained by simulation.

Firstly, we assume that the starting direction from the origin is the same on the shortest course and that this is the same after a straying driver returns to the origin. Therefore the link length from the origin to the next node is subtracted from the straying distance. Secondly, moving drivers select one direction from among four directions, namely straight, right turn, left turn, and return, at random in cases where there are no guide signs. If there are no guide signs at the intersection where a driver entered according to a previous guide sign, then the direction is selected from three directions: straight, right turn, and left turn. The direction from the origin to the next node is selected in the same way. Moreover, when a driver, who has traveled on a link with route number, crosses a link without route number and any signs, the crossed link shall not be selected as part of the course.

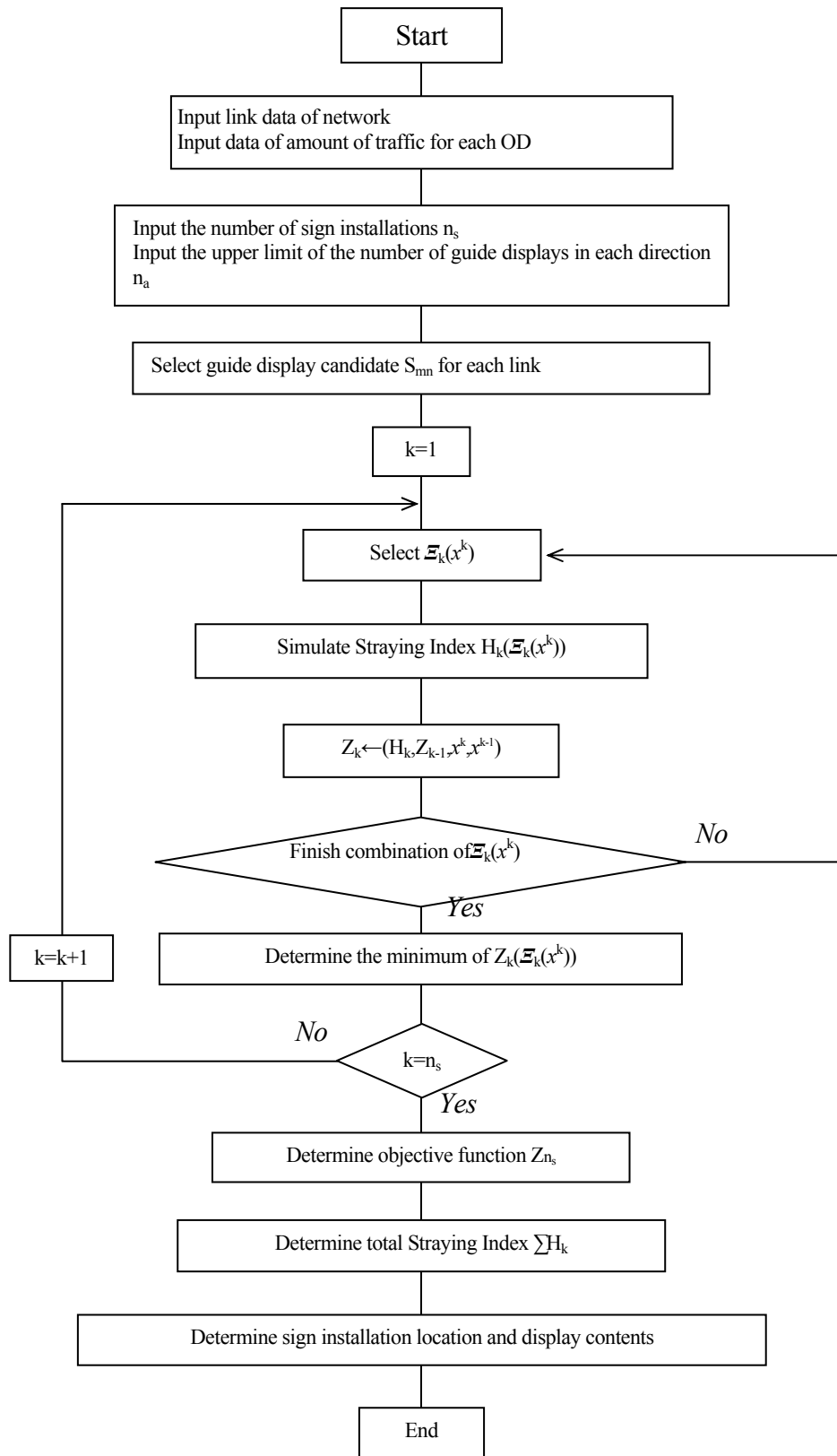


Figure 5. Flow Diagram of Solution

As for the guide contents, we firstly assume that the same place name or route number is not displayed in multiple directions on the same guide plate. Secondly, if the Straying Index is identical when either the place name or route number is used for the same OD, priority is given to

the place name guide.

4. CALCULATION EXAMPLE

(1) Example

Let us solve the problem of guide sign installation in the road network with 24 links (two-way) and 9 nodes as shown in Figure 6. We assume that the whole network with four-branch intersections uniformly expands around Figure 6. The link lengths representing time or distance are shown in Figure 7 and all the link lengths out of this area are assumed to be 1. The route numbers and their directions are shown in Figure 8 where a node number in the circle represents a place name. A number in the triangle shows a route number. A broken line represents an adjacent link outside the area of Figure 6, while a broken arrow line shows the link direction of a route when the link has a route number.

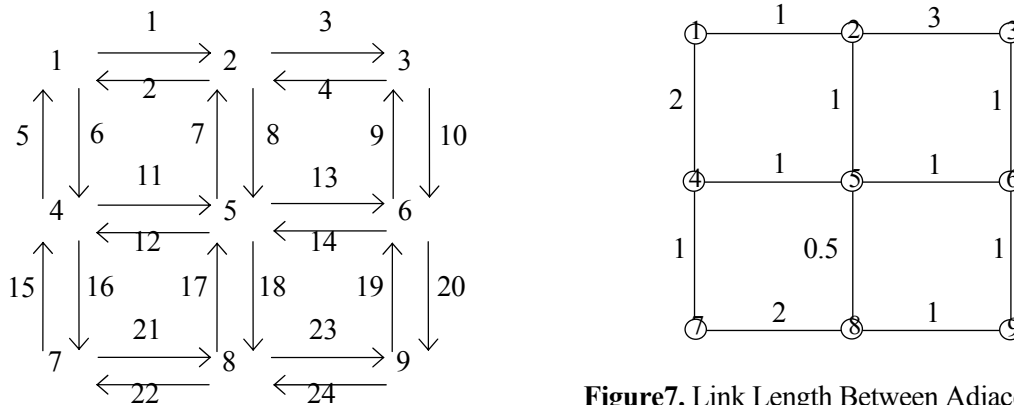


Figure 7. Link Length Between Adjacent Nodes.

Figure 6. Road Network Example (Link and Node Numbers).

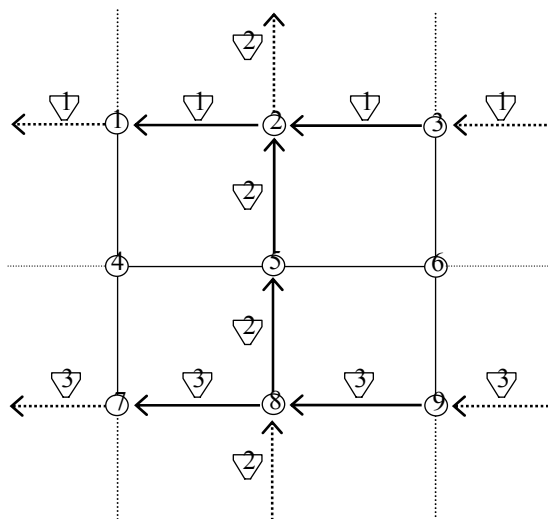






Figure 8. Route Numbers and Their Directions.

Furthermore, the left or upward direction is assumed to be "Up". It is also assumed that the amount of traffic of every OD volume is equal, and that both the upper limit n_s (the number of

sign installations) and n_a (the place names or route numbers) are 2. The set of guide candidates S_{mn} should first be found for each link. In this example, all of the place names and route numbers and the destination name on the shortest course are taken as the candidates because the area is small. Table 1 shows these guide candidates, and Figure 9 shows the shortest course of each OD.

The calculation of the evaluation function is useless in cases where the travel time ratio t_e/t_0 in the formula (9) is extremely large because the calculation time is enormous. Therefore, we adopted the value e in t_e by intervals of 10% up to the value of 50%.

Table 1. Guide Candidates

	Starting Point	Destination	Guide Candidate	
			Place Name	Route Number
OD1	7	2	4,5,2	
OD2	4	3	5,6,3	-
OD3	1	9	2,5,8,9	 ,  , 

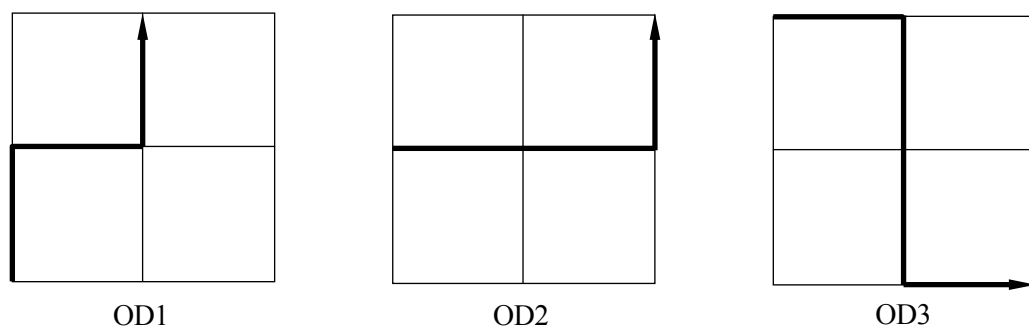


Figure 9. Basic Guide Course.

(2) Calculation Results

The calculation results of the Straying Index for three guide information in the example are shown in Table 2. The links where signs are installed and their display contents are shown in Figures 10 to 12.

Regarding the locations where signs are installed, there are the following tendencies.

- i) The signs are most likely installed on the links in the shortest course and where there are many links or many branches.
- ii) The signs are likely installed on links just before long links.
- iii) The signs are likely installed on links with a large traffic volume including other OD volumes, even if they are not on the shortest course but on a relatively short route.

Taking the OD 3 as an example hereafter, the links on the shortest course of OD 3 corresponds to i). It can be said that a link just before a short link is ineffective, contrary to ii). Link 8 corresponds to this, and therefore signs are not installed in link 8 if n_s is small. Link 13, shown in Figure. 10, corresponds to the case of iii). Although this link is on the shortest course of OD 2 and

not on the shortest course of OD 3, the destination name 9 is displayed for the right turn. It is desirable for drivers that they are guided to the destination in the shortest distance. However, when we attempt to minimize the total Straying Index, drivers are not always guided to the shortest course. This case corresponds to the drivers who are introduced to the course at the second wave or beyond in Figure 4.

Table 2. Straying Index in Example.

	OD1	OD2	OD3	Total
Without	30.25	29.75	171.12	231.12
Only Place Name	23.00	2.50	4.00	29.50
Only Route Number	2.50	29.75	8.60	40.85
Combination Type	2.50	6.00	8.60	17.10

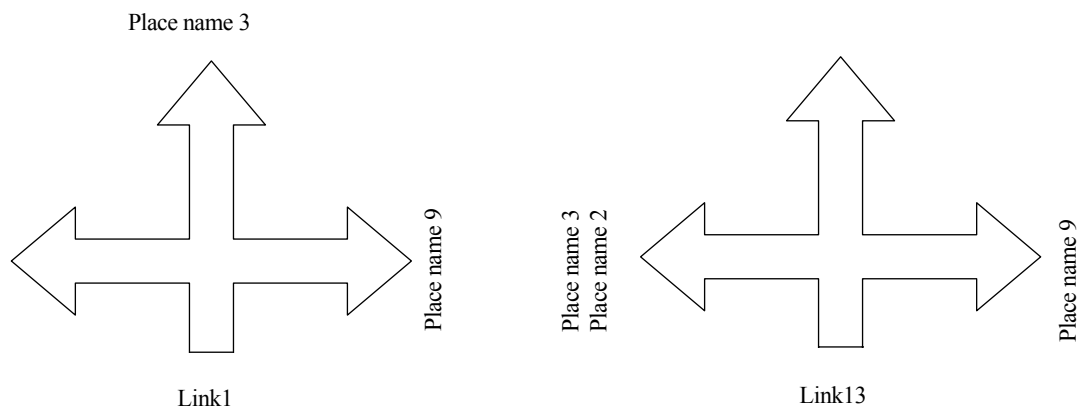


Figure 10. Guide Display Only by Place Names.

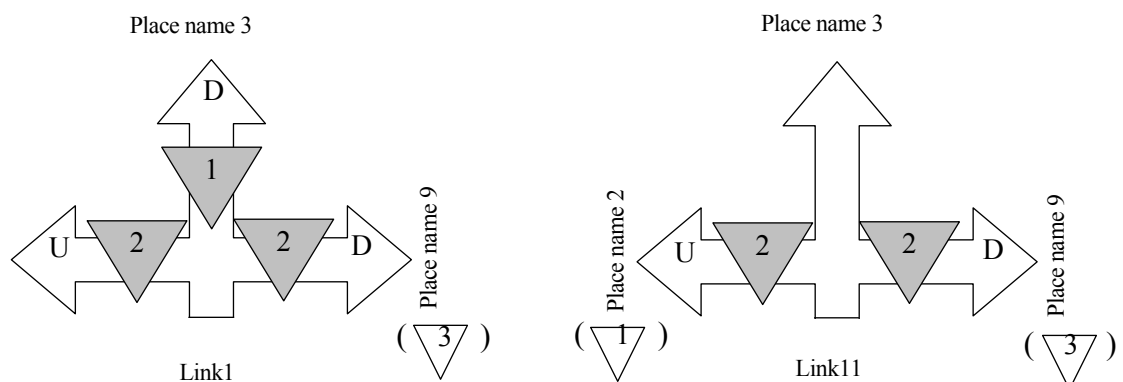


Figure 11. Guide Display of Combination Type.

As shown in Table 2, the values of the Straying Index by the place name guide, by the route number guide and by their combination for all pairs of OD are 29.50, 40.85, and 17.1, respectively. The guide effect of the combination of place name and route number is significantly high. Furthermore, link 1 and 11 are selected in the calculation result using the combination type

guide, and their display contents are shown in Figure 11. The place name 9 is selected for the right turn at link 1 and link 11 rather than the route number.

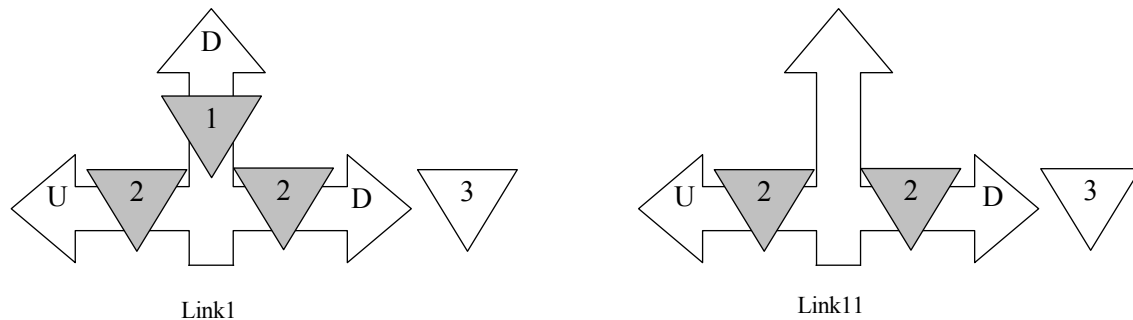


Figure 12. Guide Display Only by Route Number.

The place name 2 is selected for the left turn at link 11 rather than the route number. This is because we gave the place name priority in cases where the place name and route number have equal effect.

Now we describe the effect of displaying Up and Down.

Since the route number of link 8 and 18 on the shortest course of OD 3 is the same and this course does not cross the routes with this number, it becomes possible to continuously lead to intersection 8 by displaying [2 Down] for the right turn on link 1, as shown in Figure 12. Furthermore, this display performs an effective guide for linking with the route number after branching.

(3) Discussion

Described above, drivers are sometimes guided to links that are not on the shortest course. The reason is as follows:

In cases where continuous guides exist on all the intersections, drivers are introduced to the shortest course, and the Straying Index becomes zero. However, some links not on the shortest course are also effective, owing to the restrictions on sign installation and guide displays. Major values among the Straying Index for OD 3 are shown in Figure 13. They are obtained if the number of sign installations n_s is 1 and only the place name guide is used. The numeral in the box is the link number, the start of an arrow shows the link where the sign is installed, and the direction of an arrow shows the guide direction. The minimum Straying Index in cases where a sign is installed on link 1 of the shortest course is 25.5. As for the links other than those on the shortest course, link 3, 10, and 13 show smaller indexes than link 8 (93.4) or link 18 (55.0). This means a number of links are, unexpectedly, more effective than the links on the shortest course. Furthermore, the effective combinations obtained assuming n_s to be 2 are as follows, in order from high effect to low:

$$H_3 (\text{Link 1 right turn and link 18 left turn}) = 2.75$$

$$H_3 (\text{Link 1 right turn and link 13 right turn}) = 4.0$$

H_3 (Link 1 straight and link 10 straight) = 13.5

H_3 (Link 1 right turn and link 8 straight) = 23.75

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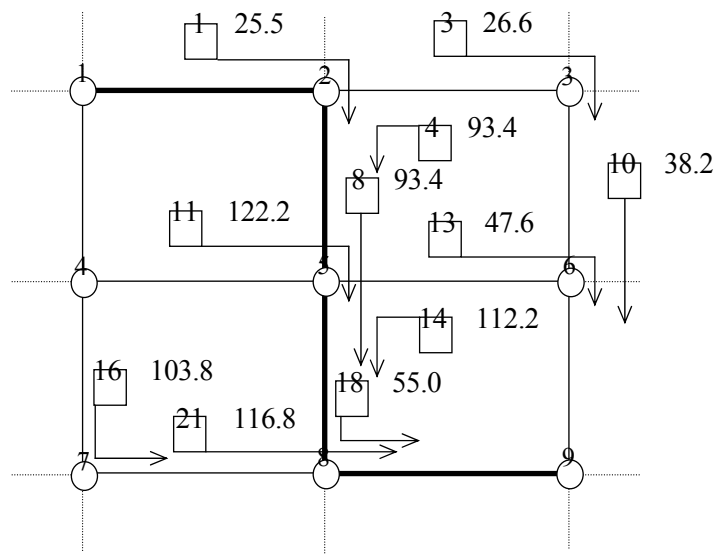


Figure 13. Straying Index of OD3($n_s=1$).

The most effective combination is link 1 and 18 on the shortest course. Among these combinations, the second and the third include links other than those on the shortest course. That is, these combinations are more effective than the fourth combination (Link 1 and 8) on the shortest course. In the example, since the total Straying Index for each OD was minimized, the second combination of links 1 and 13 (Figure 10) was selected. On link 13 the right turn with the place name 9 and the left turn with the place name 2 are displayed, but these guides do not lead any OD to the shortest course. This is because the evaluation value of formula (9) is fundamentally reduced by leading drivers, who are traveling out of the shortest course, to the destination.

Thus, this model makes it possible to construct a guide system that allows a driver who has deviated off course to return to the original course or take an alternative one.

5. SUMMARY

This study was performed to build a mathematical model and an algorithm for calculating the Straying Index and minimizing it for the optimum arrangement of guide signs in the road network.

The equation was formulated successfully in an efficient solution using dynamic programming. Furthermore, the calculation results of the small road network show the following properties:

i) Among the options of place name guides only, route numbers only, and a combination of the

two, the combination type brings the highest effect.

ii) The links on the shortest course, the links on the course having numerous branches, or the links just before long links to be selected as the most effective links. Further, some links are effective even if they are not in the shortest course.

iii) If the links of the same route number exist continuously on the shortest course and they can be distinguished from the crossing links along the way, the route number guide is very effective. If it is a continuous guide, the effectiveness increases even further.

It was confirmed that the guide sign system optimized in this study has functions not only for allowing drivers who have ventured out of the shortest course to return to the original course, but for leading drivers who had not been successfully guided to the shortest course, due to restrictions of the guide sign installations, to an alternative course. It was also confirmed that system optimization can provide an alternative route guide by minimizing the total Straying Index.

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